Software Feathers
Figurative Visualization of Software Metrics

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Abstract: In order to give the code entities of a software system a discernible and recognizable face, this paper presents *Software Feathers*, an approach for mapping characteristics of object-oriented code entities to features of artificially generated feathers. A parameterized drawing algorithm is described that generates pseudo-realistic feathers as 2D graphics. The parameters of the feathers are connected to characteristic software metrics measuring, among others, the size, complexity, and quality of interfaces and classes. Applying the approach demonstrates that categories of code entities can be discerned, problems in the code can be detected, and the evolution of code can be studied. A promising application is embedding the feathers into documentation and IDEs for improving navigation and unobtrusively educating software developers in software metrics.

1 INTRODUCTION

Besides being represented as source code, the classes and interfaces of a software system do not have a natural representation, nothing the developers look at and instantly say "ah, I remember". Code entities are unlike people and people's faces, unlike places and representation of these places on maps, unlike tunes and music: they are lacking features enabling human viewers to easily recognize them. Source code often looks uniform and repetitive; it is more predictable than natural language (Hindle et al., 2012). In order to improve this issue, the general goal of this paper is giving source code entities a figurative representation, something that is recognizable and, in the ideal case, already tells something about the characteristics of the represented piece of code—like a person's face and look tells something about the individual.

For generating a characteristic figurative representation, any shape, metaphor, or object can be employed—it only needs to have parameters changing its visual appearance. Then, characteristics of a data entity can be mapped to the visual parameters of the glyph, which creates a visualization of the entity. A well-known example are Chernoff faces (Chernoff, 1973): they represent a number of properties in parametrized features of schematic faces like the size and layout of the eyes, nose, mouth, etc. Though Chernoff faces are applicable also to software entities, this work uses a different metaphor that is not already

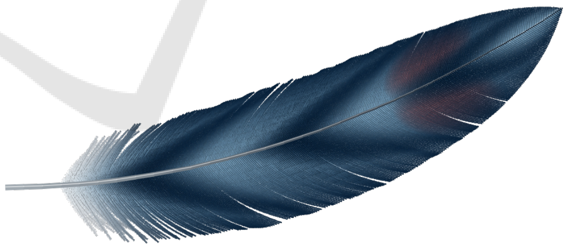

Figure 1: Visualizing a code entity as a *Software Feather*.

as overloaded with semantics and context as faces—it employs *feathers*. They have the necessary flexibility for encoding different properties in the size, shape, and texture producing unique and recognizable visual representations. Moreover, they have certain aesthetics and, in the eyes of most people, look beautiful.

In the following, I present *Software Feathers*, an approach for mapping characteristics of source code entities to attributes of a feather (Figure 1). The specific contributions of this paper are

- to describe a simple, parameterized 2D drawing algorithm for the vector-based generation of feathers (Section 4),
- to design an intuitive mapping from source code to feathers that embraces main characteristics of code entities (Section 5), and
- to explore the utility of *Software Feathers* in different application scenarios (Section 6).

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2 VISUALIZATION OF SOFTWARE METRICS

The figurative representation of software entities as feathers is a form of multivariate data visualization (Chan, 2006; Wong and Bergeron, 1997): objects having multiple attributes are depicted. More specifically, it is a glyph-based visualization technique (Borgo et al., 2013; Ward, 2008) related to others approaches such as *star plots* and similar techniques (Draper et al., 2009), which use multiple axes in a radial coordinate system, *stick figures* (Pickett and Grinstein, 1988), which encode multivariate data in the angle of sticks, or *shape coding* (Beddow, 1990), which represents multiple attributes as subcells of a data matrix. While these approaches map attributes to abstract visual properties of general shapes, the feathers approach is even more similar to more figurative techniques like the already referenced Chernoff faces (Chernoff, 1973). Also exploiting biological metaphors, for instance, Chau (2011) visualizes properties of web search results as schematic flowers or Nocke et al. (2005) propose corn cobs for depicting maize harvest data. However, it seems that feathers, so far, have not been used for encoding multivariate data.

Numeric properties of software entities are described by software metrics, for instance, object-oriented metrics (Chidamber and Kemerer, 1994), measures of code complexity (McCabe, 1976), or coupling and cohesion metrics (Briand et al., 1998, 1999). Multivariate data visualization has already been applied to software metrics: in Polymetric Views, Lanza and Ducasse (2003) propose to map up to five metrics to the size, color, and position of rectangular representations of code entities; while Polymetric Views already integrates inheritance relationships, Erdemir et al. (2011) extend the approach to further visual parameters and different types of links. Software metrics are also applied to visualizing the evolution of software. For instance, the Evolution Matrix approach (Lanza, 2001) organizes simple glyphs representing multiple code entities in a grid so that time is represented based on small multiples from left to right. Pinzger et al. (2005) integrates the time dimension into the single glyphs using star plots. Chuah and Eick (1998) propose other representations for visualizing the evolution of multiple software metrics in single glyphs, including wheel-like representations and diagrams having some visual similarity to bugs.

There also exist figurative, metaphorical visualizations of software metrics. Graham et al. (2004) applied a solar systems metaphor to software systems where code entities are represented as planets encoding software metrics in the planets' size and color. A very popular metaphor among researchers is depicting software systems as cities where stylized buildings usually represent the code entities of the system (Alam and Dugerdil, 2007; Knight and Munro, 1999; Steinbrückner and Lewerentz, 2013; Wettel and Lanza, 2008). While some approaches work with quite realistic representations of houses (Alam and Dugerdil, 2007; Knight and Munro, 1999), abstract cuboids or cylinders as employed by others may already be sufficient for encoding various metrics (Wettel and Lanza, 2008; Steinbrückner and Lewerentz, 2013). Software cities can also be used for studying the evolution of software systems: the layout of the city needs to be stabilized when showing one version after the other and buildings can be subdivided for providing information on the evolution of the system (Wettel and Lanza, 2008; Steinbrückner and Lewerentz, 2013).

It is further possible to visualize code entities as a summary of their contained source code, for instance, by plotting the pretty printed code in small font into small stripes (DeLine et al., 2006). While this approach only applies geometric zooming to the code, a higher level of aggregation is reached by summarizing each line of code as a line of pixels or even only a single pixel as demonstrated by Seesoft (Eick et al., 1992); encoding characteristics of the lines in the color of the representing pixels creates an image for each code entity. Increasing the level of abstraction, small color-coded blocks representing fields and methods provide a quick preview of code entities only requiring small amounts of screen space (Biegel et al., 2012). In Class Blueprints (Ducasse and Lanza, 2005), small rectangles representing fields and methods are visually arranged by categories and connected with dependencies; this enables the identification of categories of code entities.

3 MOTIVATION

Regarding the set of existing approaches to visualize software metrics, a legitimate question is why there is a need for yet another technique. To answer this question—hence, to motivate the approach—I want first point out some issues that are problematic when using software metrics in practice.

1. *A single metric is only able to show parts of the picture:* A single value representing a software entity only reflects a single characteristic of the entity. Multiple metrics need to be combined to provide a more comprehensive picture.

2. *Software metrics hold the danger to be over-interpreted and misused:* Metrics as numeric measures seem to be objective, but interpreting the values is difficult and subjective. It is particularly dangerous to reason only with metrics, for instance, to judge the productivity of a developer in number of changed lines.
3. *Analyzing software metrics is not an end in itself:* Software metrics are used in different applications such as detecting low quality code, finding design weaknesses, or estimating work progress. What is a good visualization of software metrics largely depends on the application.

The first observation implies that a visualization of software metrics should always present multiple metrics at the same time; using a glyph-based technique particularly addresses this issue. Further, taking software metrics not too serious and introducing a playful approach conforms to the second issue—it might prevent from over-interpretation. But most distinguishing feature of the *Software Feathers* approach is that it proposes a new application of software metrics, which has, according to the third observation, new requirements for the visualization: figurative visual representations of software entities are be generated to literally give the *invisible* software entities a face.

When integrated into documentation or IDEs, the figurative representation may support the process of visually seeking for specific entities; since large amounts of development time are spent on navigation and visual searches (Ko et al., 2006), the impact of an improved navigation process should not be underestimated. Beyond that, *Software Feathers* also provide an unobtrusive way of depicting software metrics in a compact and accessible representation, which can be used for understanding and analyzing a software system. Seeing complexity and low code quality reflected in the feathers, developers might be motivated to 'improve' the feather by optimizing the code, which introduces an aspect of gamification into software development (Passos et al., 2011; Singer and Schneider, 2012).

For creating figurative representation of code entities, using feathers as a metaphor is just one of many possible solutions; for instance, applicable as well are other natural objects such as flowers, faces, and mountains, or artificial objects such as buildings, cities, and machines. Even, feathers do not share any obvious attributes with code entities. But still I believe, that, if not the only, feathers are a good metaphor to represent software entities for several reasons: first, feathers have the necessary flexibility for encoding multiple metrics; second, a certain intuition is connected to different features of the feather such as size, shape, and condition of a feather; and last but not least, feathers are beautiful and pleasant to look at.

Hence, the *Software Feathers* approach is not just another visualization of software metrics and does not directly compete with previous approaches. *Software Feathers* rather introduce a new perspective on how to leverage software metrics for a different purpose in practice. The primary goal of the approach is to create recognizable aesthetic visual representations of code entities. In contrast to other visualization techniques, readability, clarity, and accuracy are only considered secondary design goals.

4 PARAMETERIZED DRAWING OF FEATHERS

The realistic drawing and rendering of feathers has been already investigated as a problem of computer graphics: Streit and Heidrich (2002) as well as Franco and Walter (2001) describe detailed 2D models based on Bézier curves for generating biologically plausible feathers, having similar parameters than those discussed in the following; textures of real feathers are used for coloring the surfaces. Chen et al. (2002) introduce an advanced approach modeling feathers as an L-System (i.e., a formal grammar for branching structures). They accurately simulate the fine-grained structure of feathers and capture it in a texture function; also semi-automatically building a coat of feathers is discussed.

While these approaches focus on the realistic rendering of feathers, this work uses feathers just as a vehicle for encoding information. This requires only an approach having a few simple parameters that determine the appearance of the feather, but there is no need for perfect realism. The approach presented in the following is only based on simple 2D vector graphics and does not involve any 3D rendering. Instead of using scanned textures or texture functions for rendering, feathers are rendered at full detail, including all perceivable structures of feathers.

4.1 Anatomy of a Feather

According to biologists (Podulka et al., 2004; Lucas and Stettenheim, 1972) and as illustrated in Figure 2, a feather consists of the thin **shaft** in the middle and two flat **vanes** attached left and right of the shaft. The first part of the shaft, which does not have any vanes attached, is called **calamus**; the remainder with attached vanes is referred to as **rachis**. The vanes are not solid, but are composed of many parallel **barbs**

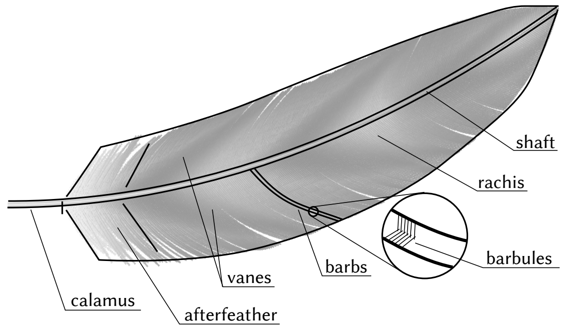


Figure 2: Anatomy of a contour feather.

branching from the rachis. While the downy part of the vanes near the calamus consists of soft barbs and constitutes the **afterfeather**, the remainder of the vanes is stiffer and the barbs agglutinate: the reason is that tiny **barbules** having **hooklets** (not illustrated) at their tips branch from the barbs; the barbules of neighboring barbs partly overlap and stick together. The feather shown in Figure 2 depicts a typical **contour feather**, an outermost feather being part of the visible coat: it is smoother than a flight feather and the additional afterfeather keeps the bird warm.

4.2 Drawing Algorithm

The drawing algorithm largely follows the biological model: all described parts are directly rendered except for the tiny hooklets, which are anyway invisible to the human eye. Central component for generating the feathers are simple polylines with varying strength and color—the shaft, the barbs, as well as the barbules are drawn as such lines. The bended shaft of the feather is simplified somewhat in comparison to the biological model: the curve follows a simple cubic parabola and and its strength only decreases linearly from the tip to the end. Analogously, the curvatures of the barbs are defined by parabolas and their outer ends become smaller.

The general contour of the feather mainly depends on the length and orientation of the barbs. The barbs start with a short initial length at the inner end of the rachis, quickly increase in length asymptotically approaching a maximum length, and finally get shorter again at the outer end of the feather. The barbs do not branch in a right angle from the rachis, but point towards the outer end of the feather with a certain default branching angle. Additionally, the barbs bend in the same direction, which further increases this effect. This layout of the barbs creates the typical contour of a feather. Maximum length of the barbs and their default angle can be different for the two vanes. Barbules become shorter towards the boundaries of the feather.

For a realistic impression of a feather, however, further details need to be considered: One effect in reality is that the vanes occasionally have gaps where barbs were separated by some force (e.g., wind). The drawing algorithm simulates these gaps by varying the branching angle of the barbs for differently sized sequences of neighboring barbs—thereby sticky blocks of barbs are created. Additionally, the branching angle is slightly varied continuously following a sinus curve with varying wave length; this models the tiny waves that the vanes would form in 3D. For generating the downy afterfeather, branching angles of barbs and barbules are varied randomly (within certain boundaries) and independently of the neighboring barbs and barbules as downy barbs do not stick together. Moreover, barbules of downy barbs are longer. Implementing a smooth transition between afterfeather and the main feather, a parameter continuously reduces the influence of the random angles and longer barbules.

Finally, the colors of the polylines need to be specified. Different species of birds show a wide variety of patterns ranging from monochrome feathers to multicolor, complex patterns. The texture applied here has a medium complexity and consists of two colors. As already discussed, the colors are not retrieved from pixel-based textures but are computed algorithmically based on the role and position of the polyline in the feather. The barbules create the main color impression of a feather. The specific color is determined by a sinus function defined on the position of the barbule (i.e., the relative position of the barb on the shaft and the relative position of the barbule on the barb) specifying the mixing proportion of the two colors. In order to create an 'eye' that some birds have in their feathers (e.g., peafowls), an elliptic area with smooth borders at the outer end of the feather is filled with a different two-color texture. To simulate some irregularities in the feather, the brightness of the barbules is varied randomly to a small extent. Barbules of the afterfeather are brighter in general.

4.3 Parameters

The described drawing algorithm has many parameters that need to be set: length attributes, line strengths, branching angles, curvatures, colors, influence of random factors, frequencies of sinus curves, etc. Arbitrarily varying these parameters creates a large variety of feathers, however, not all looking like natural feathers but becoming degenerated. In order to allow the generation of diverse, but realistic feathers, only a set of particularly characteristic parameters are proposed for variation; they can be safely modified within boundaries without producing degenerated feathers. As kinds of visual dimensions, these parameters form the basis for the later encoding of information into the feathers.

Table 1 illustrates the effect of each parameter individually. The first image, where all numeric parameters are set to a medium value, depicts the starting point for parameter variation. Most of the numeric parameters are normalized to the range of $[0,1]$, which is mapped to reasonable boundaries of the specific parameters in the drawing algorithm; the boundaries were determined by experiment. Each row of the table shows the respective feather when using the minimum and maximum value of a parameter. Additionally, the last two images provide examples for extreme parameter settings in order to show that the created feathers in general do not become degenerated.

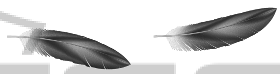
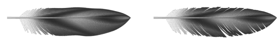
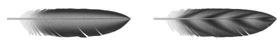
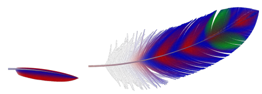
Size A pronounced feature of a feather is of course its size, which can be divided in the length of the shaft and the length of the barbs. While a long shaft and short barbs lead to feathers having a thin and pointed contour, long barbs and a short shaft create a corpulent silhouette.

Shape As a first parameter changing the shape of the feather, the symmetry of the feather can be adapted: for an asymmetric feather, the barbs of the left (outer) vane are shorter than for the right (inner) vane. Further, controlling the curvature of the shaft, the complete feather becomes bended; since bends in both directions are possible, this is a parameter with a range of $[-1,1]$. Finally, smaller adaption of the shape are the size of afterfeather, which controls the downy end of the feather, and the degree of damage, which specifies the number and severity of gaps in the vanes.

Texture For the texture, it is possible to set a base color, which is used for the outer barbules and parts of the inner barbules, and a highlight color, which is only used for remaining inner barbules. Not connecting colors to a color-scale, the color parameters are categorical. However, the frequency of the periodic pattern can be varied as a numeric parameter. Further, a secondary texture might be specified, which recursively takes another texture having a base and highlight color as well as a frequency for coloring a part of the outer end of the feather. This parameter can be used for referencing the texture of other feathers.

Other parameters could have been varied as well, such as the length of the calamus, the thickness of the shaft, the density and angle of barbs and barbules, the algorithmic pattern of the texture—just to give a few examples. However, modifying these does not change the overall appearance of the feather, may destroy parts of its natural look, or is hard to be connected with an intuition. As a consequence, these parameters do not undergo changes in the following but are set to reasonable default values also retrieved by experimenting with the visualization.

Table 1: Visual parameters of a generated feather.

parameter	type	example
default		
size		
shaft length	number $[0,1]$	
barb length	number $[0,1]$	
shape		
symmetry	number $[0,1]$	
curvature	number $[-1,1]$	
size of afterfeather	number $[0,1]$	
damage	number $[0,1]$	
texture		
base color	category	
highlight color	category	
pattern frequency	number $[0,1]$	
secondary texture	reference	
extremes		

4.4 Implementation

The drawing algorithm was implemented in Java using the processing graphics library with its Java2D renderer. In contrast to the approach of Streit and Heidrich (2002), the presented model also draws barbules and does not need to work with pixel-based textures. As a consequence, very many 2D lines need to be drawn for each feather: the particular feathers depicted in Table 1 consist each of 102,468 (small extreme feather) to 1,142,484 lines (large extreme feather). Rendering these on a Intel i5 processor (not on graphics hardware) in 960x800 resolution takes less than 550 ms per feather—too slow for animated real-time renderings but fast enough for generating feathers on demand in an interactive system. However, porting the implementation to hardware-accelerated graphics may speed up rendering and allow animated feathers.

5 SOFTWARE FEATHERS

So far, a parameterized algorithm for drawing feathers has been described. Now, mapping characteristics of code entities to the parameters transforms the drawing approach into an information visualization technique. As the targeted level of granularity, classes and interfaces of object-oriented systems are considered to constitute the set of code entities—they form the main abstraction of a system and are largely self-contained units of design. While arbitrary mappings of code characteristics and feather parameters are possible, intuitive connections, which are tried to be found and motivated in the following, make the feathers 'readable'. Figure 3 provides a labeled example of a *Software Feather* depicting the class `SDIApplication` of JHotDraw 7.6; it is a class for handling *single document interface* (SDI) applications.

5.1 Metrics and Visual Mapping

As a prerequisite for creating feathers reflecting the nature of classes and interfaces, characteristic features of these code entities need to be identified. While countless software metrics have already been proposed, the challenge is selecting a small subset of these covering different aspects of the entities, which are literally painting representative pictures. What is more, the mapping between code properties and visualization needs to be intuitive. For example, it is more sensible to represent the size of an entity in the size of a feather than in its damage. Due to the sheer amount of possibilities for selecting and mapping metrics, the following design decisions are arbitrary to some extent, but try to use the provided degrees of freedom in a reasonable way. It still can be argued that other metrics and mappings might better serve a specific purpose and should be applied instead. An important point, however, is that the mapping should be stable, that is, it should not be changed during the course of usage: viewers are enabled to learn reading the feathers and code entities become recognizable through their figurative representation.

Table 2: Mapping of software metrics to feather parameters.

software metric	feather parameter	mapping function
identity	*highlight color*	random (hash code)
package	*base color*	random (hash code)
interface or class	*symmetry*	categorical (0.2; 0.8)
#methods	*shaft length*	asymptotic ($a = 1.15$)
avg. NCSS per method	*barb length*	asymptotic ($a = 1.15$)
inheritance	*secondary texture*	reference
dependency difference (out - in)	*curvature*	asymptotic ($a = 1.1$)
percentage of hidden methods	*size of afterfeather*	–
max. cyclomatic complexity	*texture frequency*	asymptotic ($a = 1.05$)
avg. #Checkstyle errors per method	*damage*	asymptotic ($a = 1.15$)

The specific mapping proposed in this paper is introduced below and summarized in Table 2. As discussed, parameters of the feather are only modified within the boundaries illustrated in Table 1. To prevent outliers from dominating the visual appearance of the feathers, a non-linear mapping asymptotically approaching 1 is applied if the metric is not already normalized. In particular, an exponential function is used for mapping a non-negative value x to the interval $[0,1]$:

$$f(x) = 1 - a^{-x} \quad .$$

The base $a > 1$ thereby serves as a parameter for controlling the rate of increase. Experimentally derived configurations for a are also reported in Table 2 where applicable.

Identity Although it might appear trivial, the identity provided by the unique identifier of the code entities (i.e., the package name together with the name of the entity) should be considered for creating unique and recognizable images. Since class and package names do not have a natural order, they are best encoded in categorical parameters such as colors. In particular, the visually stronger base color is used for encoding the package name and the highlight color is representing the class name. Color assignments to names are random, but based on hash codes of the names; this warrants that the same entities are always assigned the same colors, for instance, when rerunning the algorithm. In Figure 3, the dark blue base

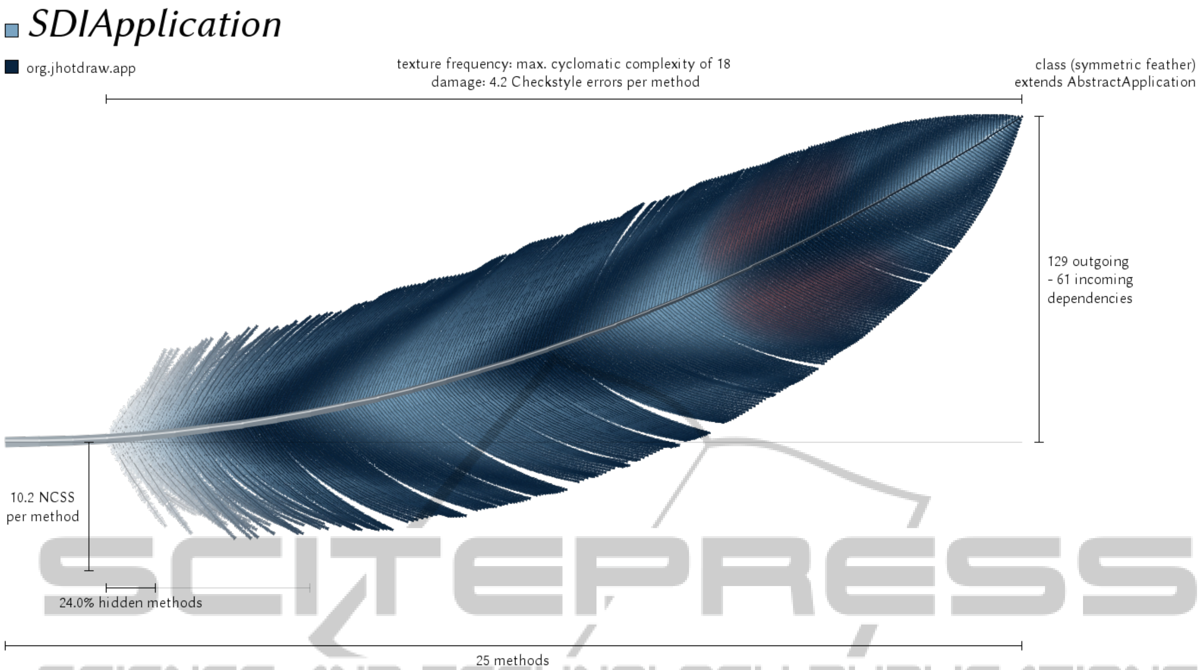


Figure 3: Labeled *Software Feather* representing the class `SDIApplication` of JHotDraw 7.6.

color encodes the package `org.jhotdraw.app` and the brighter blue highlight color represents the class `SDIApplication`.

Type For understanding the purpose of a code entity, one needs to discern whether it is an interface or class. This categorical information is mapped to the symmetry of the feather. Since the symmetry was introduced as a numeric parameter, the two categories have to be mapped to numeric values (here, 0.2 and 0.8) for visualization—the asymmetric configuration thereby represents an interface while the symmetric one identifies classes. The intuition behind this selection is that interfaces can be considered as asymmetric because they only declare methods without implementing them. As the feather is symmetric, Figure 3 depicts a class.

Size The size of an entity provides a first impression of its content and can be best depicted in the size of the feather. Instead of counting lines of code, the number of non-commenting source statements (NCSS) may provide a more appropriate size estimate. From an object-oriented perspective, also the number of methods is an interesting measure of size. While the number of methods is directly mapped to the length of the shaft of the feather, NCSS is divided by the number of methods and assigned to the length of the barbs. The normalization of NCSS prevents from encoding the total length of the source code twice, once in the number of methods and once in NCSS. With 25 methods and 10.2 NCCS per method, `SDIApplication` as depicted in Figure 3 has a medium size.

Design Diving somewhat deeper into the design of a code entity, the feather also encodes information on dependencies and visibility of methods. As a special form of dependency, inheritance connections are prominently encoded by referencing the texture of the inherited code entity as the secondary texture. Aggregating the other dependency information, the difference in number of incoming and outgoing dependencies of a code entity is mapped to the curvature of the feather; the negative or positive results are mapped to the interval $[-1, 1]$ using an analogous asymptotic mapping function as before, however, preserving the sign of the value. This mapping provides an overall impression of the role of the code entity in the dependency graph of the system. The percentage of hidden methods (visibility modifiers `private` or `protected`) is encoded in the size of the afterfeather; since this percentage value is already normalized to the interval $[0, 1]$, applying a mapping function is not necessary. Class `SDIApplication` in Figure 3 inherits class `AbstractApplication` identified by the red 'eye'; pointing upwards, the class has much more outgoing than incoming dependencies; the small size of the afterfeather indicates that only some methods are declared `private` or `protected`.

Quality Finally, some quality attributes of the code entities should be considered: On the one hand, the complexity of a code entity is taken into account, here, measured as the maximum McCabe's cyclomatic complexity (McCabe, 1976) of all contained methods. It is mapped to the complexity of the texture, that is the frequency of color changes. On the other hand, conformity to coding standards is checked and reported in form of the number of violations/errors that the Checkstyle[1] tool finds applying the standard Java conventions. Mapping these in relation to the size of the entity (here, the number of methods) to the damage of the feather provides an impression of potential coding problems in the code entity. The feather in Figure 3 shows that class `SDIApplication` has a quite high maximum complexity and contains a number of coding issues.

5.2 Implementation

While the underlying *Software Feathers* approach can be applied to any object-oriented system, the implementation focuses on Java systems. Several libraries are used for retrieving the required code metrics: JavaNCSS[2] for the NCSS metric and the cyclomatic complexity, DependencyFinder[3] for the number of incoming and outgoing dependencies, and Checkstyle for the number of coding standard violations. An additional code processor retrieves inheritance, the type (class or interface) of a code entity, and the number of (hidden) methods.

Since it might be bothering to learn the mapping from a textual description or a table, a labeling algorithm was implemented and already used for creating the labels in Figure 3. Labels also provide the precise numbers of the metrics. The goal for labeling was to present the required information close to the feather. While this was possible for some of the labels, other information such as colors, symmetry, and inheritance is only provided as a legend at the top because these attributes globally apply to the complete feather.

6 APPLICATION

To test the utility of *Software Feathers* and to discuss possible application scenarios, the approach is applied to visualizing JHotDraw[4], an open-source Java graphics framework. As JHotDraw was also implemented to provide an example of a well-designed software, it often acts as a kind of benchmark for software engineering approaches. By depicting the code entities as *Software Feathers*, Figure 4 provides an overview on the complete project in version 7.6, which includes 578 classes and interfaces (ignoring inner classes, anonymous classes, code entities without methods, and external library code). The entities are arranged in columns and ordered lexicographically by their fully qualified name from top to bottom and from left to right. Larger, labeled versions of all feathers are available online[5].

Figure 4: All code entities of JHotDraw 7.6.

[1] `http://checkstyle.sourceforge.net/`
[2] `http://www.kclee.de/clemens/java/javancss/`
[3] `http://depfind.sourceforge.net/`
[4] `http://www.jhotdraw.org/`
[5] `http://softwarefeathers.fbeck.com`

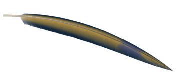
6.1 Recognizability of Feathers

Visually comparing the feathers of Figure 4 to each other, it is possible to discern individual feathers. Despite the large amount of listed feathers, it is even possible to recognize individual ones. Of course, it neither can be expected that users learn all more than 500 feathers nor that certain similar feathers are not mistaken one for the other. But considering that software engineers usually focus their current work on smaller subsets of entities, the discernibility of feathers probably is good enough. Moreover, similarity is intended if the code entities share certain characteristics. For instance, judging by the base color, it is possible to easily retrieve the neighboring feathers that belong to the same package. Further similarities can be retrieved analogously by looking for similar size, shape, or texture. Ordering feathers by package as done in Figure 4 shows that often code entities with similar characteristics are contained in the same package. Literally, code entities—not birds—of a feather flock together.

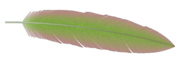
6.2 Categories of Feathers

Investigating the similarities of feathers in greater detail, code entities are classified into different categories that can be easily discerned by briefly looking at the feathers. These categories of classes and interfaces are somewhat similar as those discussed for the Class Blueprint approach (Ducasse and Lanza, 2005); those, however, investigate a much more fine-grained level of detail.

Central Class Classes controlling and implementing essential parts of the system form the central classes of the system. They usually consist of many functions (long shaft) having a reasonable length (high length of barbs) and complexity (high texture frequency); since they control the system, they have more outgoing than incoming dependencies (upward curvature). The depicted example shows the `OSXApplication` class, which combines multiple views as a Mac OS X application.

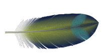


Important Interface In general, interfaces can be discerned from classes easily because of their asymmetric contour. By definition, they contain only method declarations, which results in short barbs and low texture frequency. Interfaces of particular importance might be those declaring many methods (long shaft) used by many other code entities (downward curvature). Abstract classes only implementing a few methods but declaring many others might also play a similar role and show similar, but symmetric feathers. The depicted example shows the `View` interface, which defines the central interface of a view in the GUI of JHotDraw.



Data Class The data that is processed by a software is often stored in member variables of dedicated data classes. Following the the best practices of Java programming, the visibility of the member variables are set to `private` and the data is accessed through getter and setter methods. As a consequence, data classes have a low complexity (low texture frequency) and a reasonable number of short methods (long shaft, short barbs). Moreover, being used by many other classes of the system, data classes often have more incoming than outgoing dependencies (downward curvature). The depicted example shows the `Polygon2D` class which stores the data of a two-dimensional polygon and provides accessors for the data.

Implementation Detail Complex implementation details are often hidden in classes consisting of a number of complex and long private methods (high texture frequency, long barbs, long afterfeather). Moreover, the respective class is likely to be more accessed by other classes than relying on functionality of others (downward curvature), which discerns it from a *central class*. The depicted example shows the `ColorSliderUI` class implementing the details of a color slider component.



Concretization Working with inheritance, a form of generalization is introduced. The inheriting classes or interfaces concretize the general one (secondary texture) often by only overriding or implementing only a few methods (short shaft) with limited complexity (low texture frequency) and length (short barbs). These concretization classes, hence, can be identified by looking for small feathers with a plain main texture but a spot with a secondary texture. The depicted example shows the `CloseFileAction` class, which extends the `AbstractSaveUnsavedChangesAction` class by overriding the constructor and implementing a single method for performing the respective action.

However, in practice, many code entities cannot unambiguously assigned to a single category but form

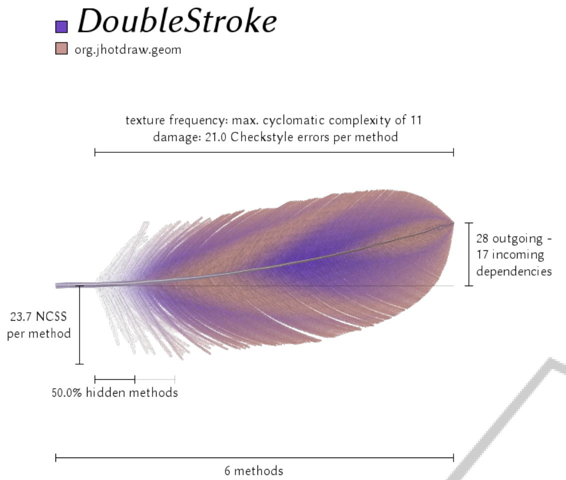


Figure 5: Class `DoubleStroke` of JHotdraw 7.6 possibly containing coding problems.

a mixture of multiple categories. Nevertheless, the visualization is capable of reflecting these combinations as the feather also becomes a mixture of the described feathers representing the categories. Further, the introduced categories may act as a dictionary for translating feathers into the language of software engineers. Like ornithologists certainly are able to directly discern a feather of an owl from a feather of an eagle, users of *Software Feathers* might quickly learn to read the main characteristics or category of a code entity from the respective feather.

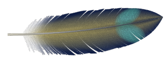
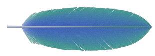
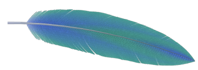
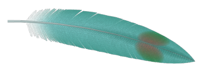
6.3 Coding Issues

Besides discerning categories of code entities, *Software Feathers* might also support finding problems in the code, so called *bad smells* (Fowler et al., 1999). Potential issues that can be detected are *long methods* (long barbs, high texture frequency) and *large classes* (long shaft). Also pure data classes as described above can be considered as code smells (Fowler et al., 1999). Further, the damage of the feather visualizes the violation of coding standards, which is another unwanted property of the code. The class `DoubleStroke` as depicted in Figure 5 provides an example for a class that might be worth revising: it has long methods, many Checkstyle errors, and a considerable complexity.

6.4 Evolution of Code Entities

Software Feathers, as compact representations of code entities, are further applicable to comparing multiple revisions of the same entities. Table 3 provides a few examples comparing entities from JHotDraw version 7.0.6 to version 7.6. Since JHotDraw 7.0 is a complete reimplementation of previous versions, still many things changed from the early version 7.0.6 to the current version 7.6. As a consequence, many files were added or moved during this time. For instance, class `ClearRecentFileAction` became `ClearRecentFilesMenuAction`—the feathers as depicted in Figure 3, however, show that the characteristics of the file did not change much in general, but that the class was also moved to a different package (change of base color). Other code entities such as the `ColorIcon` class changed some characteristics but not their name or location. Only a few entities stayed largely unchanged as, for instance, the `AbstractApplicationAction` class.

Table 3: Evolution of code entities.

JHotDraw 7.0.6	JHotDraw 7.6
`ClearRecentFilesAction` 	`ClearRecentFilesMenuAction` 
`ColorIcon` 	
`AbstractApplicationAction` 	

Beyond performing pairwise comparisons, *Software Feathers* can easily be used for representing more versions of an entity on a timeline or for showing the evolution of a small sets of entities in a table like proposed by Evolution Matrix (Lanza, 2001). Continuously interpolating the parameters of the feathers from one version to the other, it is as well possible to produce animatedly evolving feathers.

6.5 An Integrated Application Scenario

As demonstrated above, working with *Software Feathers* as a standalone approach provides the means for getting an overview and a rough understanding of an unfamiliar project. Software developers having already a deeper knowledge of a system can profit from the visualization by finding coding issues and unexpected properties. Nevertheless, treating *Software Feathers* as a standalone approach leverages only parts of its potential utility. In particular, considering that a small version of a feather may act as an icon or thumbnail representing a code entity, further areas of application become apparent: *Software*

Feathers can be integrated into software engineering tools replacing standard icons with individual feather icons for the represented code entities. For instance, in an IDE, feather icons can be used in tree views of the project structure, as headers of editor tabs, or in search results.

It is further possible to augment the raw source code as presented in an editor view by *Software Feathers*. Feather may accompany the declaration of each class and interface in larger size and might even enrich each usage of a class or interface as tiny thumbnails. Details such as a labeled feather can be provided as tooltips. This constitutes a form of in situ software visualization as already proposed for schematic diagrams visualizing line-based metrics (Harward et al., 2010), code smells of methods (Murphy-Hill and Black, 2010), states of numeric variables (Beck et al., 2013a), or method runtime consumption (Beck et al., 2013b).

These ideas of tool integration finally exploit the recognizability of the feathers in order to provide enhanced orientation in IDEs, documentation, and other user interfaces showing code entities. When using feathers consistently, the approach even might link diverse tools closer through recognizability of code entities. The integration promises to ease code navigation as entities can be retrieved more quickly and feathers provide a preview on unknown entities; as Ko et al. (2006) found, developers might spent 35% of their time for code navigation.

7 CONCLUSIONS

Software Feathers are a technique for figurative visualization of code entities. Applying the metaphor of feathers to software systems, they provide a playful approach to software metrics. By mapping important characteristics of code entities in the parameters of the rendering procedure of feathers, unique images are created for each entity. They provide the originally 'invisible' software artifacts with a recognizable 'face' and promise to be suitable in different applications: specifically, simple categories of feathers give a quick outlook on the purpose of the represented code entity. This enables finding interesting code entities, gaining an overview of a project, or studying the evolution of code entities. Future research questions will be how quickly users learn to read *Software Feathers*, how far having feathers integrated in the IDE improves orientation and eases code navigation, and whether *Software Feathers* increase the motivation among developers to consider and use software metrics.

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